8-1-1993

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Abstract—Developing countries often tax agriculture heavily, a practice that might affect the productivity as well as the quantity of resources allocated to agriculture. A variable-coefficient cross-country agricultural production function is estimated, with past price expectations among the determinants of the production coefficients. Productivity's responsiveness to those expectations implies that had these developing economies eliminated price interventions, agricultural productivity would have increased on average by about a fourth.

IN agriculture, as any other sector, output prices affect the amount of resources allocated to aggregate production. According to a review by Binswanger (1989) these movements along the supply function reflect an elasticity of about 0.1–0.3. But from decade to decade over this century, there has been virtually no relationship between agricultural output and the amount of resources allocated to it (at least as resources are traditionally measured). The real engine of growth in agricultural output is technical change, not output price. Since Schultz (1956) brought this phenomenon to our attention, there have been many studies examining this technical change—its rate, whether it is factor-augmenting, its input bias, whether it can be captured by appropriate quality adjustments in measuring inputs, to what extent it is determined by government research, etc. But it is a little surprising that, to date, there has been virtually no attention given to the question of the role of prices in determining the rate of technical change. Could we believe that prices affect individuals' choices in almost every realm of life but not those choices that determine the rate of technical change?

This question is of particular significance for the development of agriculture in the less developed countries. While the development community has devoted considerable attention to the issue of getting prices right for a reasonable allocation of resources to agriculture, it might be as important to get prices right for technical change. In this study we estimate from time series data in eighteen LDCs that a 10% increase in output price will increase productivity by a little over 1%, in addition to the 1% to 3% allocative effect indicated by Binswanger. The productivity effect is, of course, more significant in that it represents an enhanced level of output in perpetuity, rather than for just the period of higher price.

The paper begins with a review of literature bearing on the relationship between prices and productivity, which yields little in the way of theoretical or empirical consensus. Then a theory is sketched which results in a production function specification which posits that past prices can indeed determine current levels of productivity. The production function is estimated using time series data from eighteen LDCs. Finally, recent estimates of the tax wedges against agriculture in these countries are utilized to examine the potential productivity effect that might have occurred through the lower prices.

I. Innovation, Efficiency, and Prices

This study is addressed to the issue of productivity in agricultural sectors. Although productivity is a concept with some ambiguity, we accept the general notion that productivity has increased when output from a given level of inputs has increased. Such productivity increases might occur either because of an improvement in the technical efficiency with which the inputs are used or because of innovations in technology (Fare et al., 1988). What should we expect to be the effect of prices on either efficiency or on technical change? Previous literature has devoted little attention to the question.

Innovation has come to be considered an activity to which firms allocate resources according to its profitability (see Dosi (1988) for a review of the innovation literature). This profitability can be affected by factors affecting the supply of innovations, such as the existence of new knowledge or the costs of research, or by demand-side factors such as price changes or appropriability changes. The Schmookler-Lucas hypothesis derived from this conceptual approach is that higher

Received for publication October 23, 1991. Revision accepted for publication May 28, 1992.

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The authors would like to thank two anonymous referees for helpful suggestions, while not implicating them for any errors remaining. Journal Paper No. J-14462 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 2998.

product price (or product demand) should increase the level of innovation.[1] Huffman and Evenson (1989) provide evidence supporting the Schmookler-Lucas hypothesis for the U.S. agricultural sector. But the firm-theoretic basis for these empirical results is not so clear. Binswanger (1978) developed an explicit model of the firm which showed that innovation would increase with expected output price, but only if the optimal output is expected to increase because of the innovation. The theoretical relationship between input prices and the rate of innovation seems not to have been explored, though relative input prices have been presumed to affect the input bias of innovations. Mundlak (1988) argues that prices are one of the state variables that determine the choice of technique and therefore productivity, but he does not offer a hypothesis regarding the sign of such a relationship.

The literature on efficiency also suggests a role for price. Hicks (1935, p. 8) suggested that monopolists with the luxury of the "quiet life" might be technically inefficient, and Leibenstein (1973) added that within firms with market power, managerial motivation may be so lacking that technical inefficiency may be a significant source of reduced productivity. Thus, in this view, as competitive pressure forces prices lower, incentives for managers to improve technical efficiency (or to innovate, for that matter) are greater because the firm's survival is threatened. This "quiet-life" hypothesis, a negative relationship between output price and productivity, is thus exactly the opposite of the Schmookler-Lucas hypothesis. A number of studies have offered empirical support for this hypothesis.[2]

[1] Schmookler's (1966) empirical results showed a positive relationship between the number of patents issued and increases in product demand, across U.S. industry groups. Lucas (1967) estimated a negative regression relationship between the rate of growth of factor productivity and the ratio of input prices (labor and capital) to output price, also across U.S. industry groups.

[2] Bergsman (1974), for example, examined the effects of import protection in six countries and calculated that the cost of protection included productivity reductions equal to from 2% to 6% of GNP. Martin and Page (1983) estimated a frontier production function for logging and milling industries in Ghana and found that public price subsidies reduced productivity. In agriculture, Kalaitzandonakes and Taylor (1990) found that the average rate of productivity growth for a set of Florida vegetable crops with no import competition was 1.6% per year, whereas the average rate for a set of similar crops competing with Mexican imports was 5.1%.

Given the competitive structure of agriculture, there seems little a priori likelihood that the "quiet life" hypothesis would prevail, except perhaps in relatively small, highly concentrated specialty commodities such as those examined by Kalaitzandonakes and Taylor. A number of observers of the agricultural economy have in fact asserted the existence of a positive relation between prices and productivity. Schultz (1979) argued that from his observations it is clear that the higher are prices in agriculture, the faster the rate of productivity growth. Schuh (1974) argued that the overvalued U.S. dollar depressed U.S. agricultural prices, which in turn reduced the rate of technological innovation. But as Capalbo and Antle observe, "We know of virtually no research that has attempted to account for the effects of government intervention or regulation in agriculture on the measurement and explanation of agricultural productivity . . . [even though] . . . we would expect that government policies may have substantial effects on agricultural productivity."

II. An Endogenous Technology Approach to Productivity

According to Dixit (1976), a technique is a particular combination of inputs producing a particular output, i.e., a production process. We define the collection of all available techniques, as described by an isoquant map or a production function or indirectly by a cost function, as the technology available at a point in time. When new techniques become available as a result of new knowledge, technology changes. Our objective here is to develop a model of production within which the technology embodied is to some degree endogenous and responsive to previous choices. Our general approach is to posit a production function[3] for which the coefficients are variable and determined at any one place and time by those previous choices, and the current technological, natural, and institutional environment. We refer to these as the technology chang-

[3] An alternative to this primal approach would be to identify technical change by estimation of the dual supply and derived demand relationships. But this is not empirically feasible for the eighteen countries we examine, however, because price data are not available for several of the inputs we consider (land, livestock, and machinery).

ing variables.[4] The focus of this paper is on the effect of prices as technology changing variables. Other technology changing variables of interest are those related to the quality of the natural and human resource endowments.

The idea of prices as an argument of a production function requires some justification. Our rationalization is straightforward. If it is true that prices serve as an incentive for innovation and for the adoption of new innovations as the literature reviewed above suggests, then the price regime of one period must in some way affect the technology relevant to a subsequent period. In terms of a meta-production function, we argue that any new technique (technical change) can be described in terms of a unique combination of inputs if inputs are sufficiently narrowly defined and distinguished. Then one can specify the meta-production function as $y_t = f(x_{1t}, x_{2t})$, with x_{2t} being a very long vector of specific inputs (such as one-row cultivators, IR-8 rice, DDT, and other "techniques," in Mundlak's terms) that are individually either unknown at a point in time or unobservable by the researcher. Over time, new inputs in the vector x_2 are discovered and adopted, old ones are discarded. If prices are one of the factors determining this innovation process, then prices can serve as a proxy for these unobservables, i.e., one might reasonably express their current values as a function of previous prices: $x_{2t} = g(p_{t-1})$, and thus $y_t = f(x_{1t}, p_{t-1})$.

A. General Model

In this paper we assume the production function

$$y = f(x; \beta) \tag{1}$$

to be a real-valued function characterizing the maximum amount of y which can be produced from any given set of conventionally measured inputs $x = (x_1, \ldots, x_n)$ where β designates the vector of all parameters. Let τ_k, $k = 1, 2, \ldots, m$ represent technology changing variables that determine the production function parameters according to

$$\beta_i = G_i(\tau_1, \ldots, \tau_m). \tag{2}$$

As mentioned above, the technology changing variables can be related to the quality of natural and human resources as well as to technical change that is proxied by past price regimes or other policy variables. We introduce the concept of elasticity of productivity with respect to the τ_i's, defined as

$$\psi_k \equiv \partial y/\partial \tau_k(\tau_k/y), \tag{3}$$

which indicates the percentage by which a productivity index (percentage output change with inputs fixed) would change in response to a 1.0% change in τ_k.

It is not just the productivity effect that is of interest, but also the input bias effects of the technology changing variables. Pair-wise bias we define to be the log of the change in the ratio of marginal products of the two inputs in question. Thus, we define the bias induced by technology changing variable τ_k as the change in the log of the ratio of marginal products:

$$B_{n,i,\tau_k} \equiv \partial\{\log \partial y/\partial x_n - \log \partial y/\partial x_i\}/\partial \tau_k,$$

or

$$= \partial \log \mathrm{MRS}_{i,n}/\partial \tau_k, \tag{4}$$

where MRS is marginal rate of substitution between input i and input n. If B_{n,i,τ_k} is positive, an increase in τ_k will increase the marginal product of input n more than that of input i, and the use of input n will increase relative to i, ceteris paribus. A measure of the net bias effect of τ_k with respect to input n we define as

$$B_{n,\tau_k} \equiv \sum_{i=1}^{n} \beta_i B_{n,i,\tau_k}, \tag{5}$$

where β_i is the production elasticity with respect to input i, i.e., $\beta_i = \partial y/\partial x_i(y/x_i)$.

In the general case, the elasticities (3), (4), and (5) with respect to the technology-changing parameters may be variable and depend upon all of the quantities of inputs $x_1, \ldots, x_n$ and all of the technology-changing variables.

B. A Cobb-Douglas Specification

In this paper the following algebraic class of production functions is considered:

$$y(x; \beta) = A \prod_{i=1}^{n} x_i^{\beta_i}, \tag{6}$$

[4] Mundlak (1988) has proposed a similar approach, using the term "state variables" rather than technology-changing variables. Mundlak's approach endogenizes the choice of techniques within one period but does not allow for changes in the technology set, i.e., technical change. This paper departs from his approach by relaxing this assumption and by focusing on the determinants of change in the technology set.

where

$$\log A = \alpha_0 + \sum_{k=1}^{m} \alpha_k \tau_k + \mu_0, \quad k = 1, \ldots, m, \quad (6a)$$

$$\beta_i = \gamma_{i0} + \sum_{k=1}^{m} \gamma_{ik} \tau_k + \mu_i, \quad i = 1, \ldots, n, \quad (6b)$$

where y is the maximum output producible from a given vector of n inputs, x, τ_k's are the technology changing variables, α's and γ's are fixed coefficients, μ_0 is a random variable distributed independently of the x_i's and τ_k's, and the μ_i's are random variables independent of the τ_k with mean zero and a finite positive semi-definite covariance matrix. Thus, the β_i's here represent a variable elasticity of output with respect to each of the input variables x. The technology-changing variables τ determine the production elasticities and are taken by the decision makers as parameters for the current production period. Expressing equation (6) in logs we obtain the convenient econometric model:

$$\log y = \alpha_0 + \sum_{k=1}^{m} \alpha_k \tau_k + \sum_{i=1}^{n} \gamma_{i0} \log x_i + \sum_{i=1}^{n} \sum_{k=1}^{m} \gamma_{ik} \tau_k \log x_i + \sum_{i=1}^{n} \mu_i \log x_i + \mu_0. \quad (7)$$

This model allows us to evaluate directly the impact of past price policies on the technology. The elasticity of productivity of the technology changing variables, including past prices, for this function is evaluated from (3) as

$$\psi_k = \tau_k \left(\sum_{i=1}^{n} \gamma_{ik} \log x_i + \alpha_k \right). \quad (8)$$

If technology changing variable τ_k is expressed as the log of some variable, say z_k, then the elasticity of productivity with respect to z_k is simply

$$\psi_k = \sum_{i=1}^{n} \gamma_{ik} \log x_i + \alpha_k. \quad (8a)$$

The effect of past prices on current productivity is thus summarized by this productivity elasticity. To the extent that policies affected those past prices, the productivity effect of those policies can be measured using ψ_k.

The production elasticities as specified in equation (6b) depend on the level of the variables that condition the individual's choice, so they differ by observation.[5] The quality of available resources, the set of techniques available for production, and past price expectations will combine to determine the productivity of each input.

The bias parameters introduced in equations (4) and (5) determine if increases in the technology changing variables have neutral or biased effects on input use. The pair-wise bias parameters for the production function (6) may be evaluated as

$$B_{n,i,\tau_k} = \gamma_{nk}/\beta_n - \gamma_{ik}/\beta_i. \quad (9)$$

A zero pair-wise bias parameter value implies Hicks neutrality, while a positive (negative) value implies an n-using (n-saving) technological change from an increase in τ_k. The net bias parameter for the production function in (6) is evaluated as

$$B_{n,\tau_k} = \sum_{i=1}^{n} \beta_i B_{n,i,\tau_k} = (\gamma_{nk}/\beta_n) \sum_{i=1}^{n} \beta_i - \sum_{i=1}^{n} \gamma_{ik}. \quad (10)$$

A positive (negative) B_{n,τ_k} value implies that increases in the technology changing variable τ_k will increase (decrease) the cost share of input n.

We now use this approach to measure the effect of past price policies on agricultural productivity in a set of 18 developing countries.

III. An Application: Agricultural Protection and Productivity in Eighteen LDCs

We have selected for this study a set of 18 countries for which recent World Bank studies have made considerable data available (for more detail see Elisiana, Fulginiti, and Perrin, 1991). Table 1 lists these countries, the years for which

[5] If the technology changing variables were to include contemporaneous prices, this model would imply nonuniqueness in the relation between the marginal rate of substitution and the corresponding price ratios, in contrast to neoclassical theory. While that is not the case for the present application, the possibility resurrects an issue addressed by Joan Robinson, who argued for production models allowing reswitching, meaning that a technology may be more profitable than other technologies at more than one set of relative input prices (Harcourt, 1969).

TABLE 1.—AGRICULTURAL PROTECTION AND GROWTH, 18 COUNTRIES

Countries	Years	*NPR*[a] (%)	Production growth[b] (%)
Argentina	61–84	−40	2.1
Brazil	69–83	−13	3.8
Chile	61–83	−25	1.8
Colombia	61–83	−33	2.8
Dominican R.	66–85	−40	2.8
Egypt	64–84	−53	2.7
Ghana	58–76	−24	1.1
Ivory Coast	61–82	−53	5.2
Korea	61–84	16	4.2
Malaysia	61–83	−18	3.3
Morocco	63–84	−34	4.0
Pakistan	61–84	−47	3.8
Philippines	61–82	−32	3.8
Portugal	61–83	−18	−0.1
Sri Lanka	61–85	−49	2.1
Thailand	61–84	−41	4.7
Turkey	61–83	−36	2.8
Zambia	66–84	−53	2.2

[a] *NPR* = nominal protection rate = (domestic price/border price) − 1, adjusted for exchange rate misalignment and protection to industry.
[b] Calculated from FAO production indexes.

we examined each and the average level of agricultural protection during the period. The protection rates include the price effects of both direct commodity price interventions and the indirect agricultural price effects of real exchange rate distortions and protection afforded to nonagricultural commodities. The simple average total discrimination against the sector amounts to 37%.

Agricultural output will be reduced by interventions of this size (except in Korea who provided net protection to the sector), because of re-allocation of resources away from agriculture. But our concern is whether the productivity of resources allocated to the sector is also affected. To estimate the productivity effect of price distortions we first fit the production function in equation (7) using pooled data for these countries, and then use the parameter estimates along with estimated price distortions to calculate estimated agricultural productivity effects of past price policies. The elasticity of productivity (equation (8)) multiplied by the percentage of price distortion will indicate the shift that would have occurred in the production function if past prices had been at border prices, as opposed to the protected levels determined by past policies.

A basic assumption here is that all countries have access to the same technology, and that they thus share a common meta-production function. Such cross-country production functions have been the subject of a number of papers.[6] The present study examines a longer time series than the earlier ones, considers a different set of countries, and is the only one to incorporate prices. The study by Mundlak and Hellinghausen (1982) was the only previous effort to explicitly specify a variable coefficients Cobb-Douglas production function. In that study the coefficients were determined by variables representing the country's resource endowments.

A. *Empirical Estimates*

Data: The main empirical concern of this paper is growth in aggregate productivity, as opposed to growth in production. We measure productivity as the rate of change in total factor productivity, which is essentially the residual difference between observed output growth and the output growth predicted by observed input growth. This measure of productivity is, of course, not without ambiguity in that one may arbitrarily reduce productivity differences measured in such a way by adjusting observed input quantities to account for "quality" changes. One logical response to this ambiguity is the position that all technological change must be embodied in some input, with the implication that if inputs and input quality are correctly measured, then the measured change in total factor productivity will be zero (for example, Schultz (1956)). Because our interest in this paper is to measure differences in output for a given amount of conventionally measured inputs, our approach is to account for changes in the productive quality of these inputs by introducing separate variables such as schooling of workers and an index of land quality.

A distinction is made in the previous section between inputs and technology-changing variables. The former consist of traditionally-measured physical inputs, whereas the latter consist of measures of qualities of these inputs, prices, and research effort. To achieve comparability with

[6] The series started with a study by Bhattacharjee (1955), followed by a series of studies by Hayami and Ruttan and their associates (Hayami (1969), Hayami and Ruttan (1970), Nguyen (1979), Yamada and Ruttan (1980), Kawagoe, Hayami and Ruttan (1985)). Evenson and Kislev (1975), Mundlak and Hellingshausen (1982), Antle (1983), and Lau and Yotopolous (1989) examined countries and/or variables which differed from the Hayami and Ruttan series of studies.

other studies, we use the same input variables as those in the Hayami and Ruttan series of studies. The variables in the data set consist of

Output (y): Value of agricultural production in millions of 1980 "international" dollars.[7]

Land (x_1): Thousands of hectares of arable and permanent cropland and permanent pastures.

Livestock (x_2): Number of cow equivalent livestock units as calculated by Hayami and Ruttan.

Machinery (x_3): Agricultural tractors and garden tractors (FAO) in thousands of horsepower units, aggregated according to Hayami and Ruttan's procedures.

Fertilizer (x_4): The sum of nitrogen, potash, and phosphate content of various fertilizers consumed, measured in thousands of metric tons in nutrient units.

Labor (x_5): Thousands of participants in the economically active population in agriculture.[8]

We distinguish three types of technology changing variables: those related to past price expectations, those related to the introduction of new techniques, and those related to the quality of the country's endowments. As proxies for them we have used:

Output price (τ_1): Five-year moving averages of Tornquist indexes of prices received for major agricultural products, as reported by the World Bank. Price indexes were constructed as follows. Tornquist indexes were constructed for each country, using deflated domestic currency price series for the relevant commodities. Then for 1980, a cross-country price index was constructed as a Tornquist index value for each country relative to a base consisting of the 18-country average price and quantity for each commodity (prices converted to dollars at the 1980 official exchange rates). The domestic price index series for each country was then divided by the 1980 cross-country index value for that country.

Wages (τ_2): Five-year moving averages of monthly wages in U.S. dollars paid to agricultural workers. The deflated wages for each country were divided by a 1980 cross-country index consisting of the 18-country wages weighted by employment.

Fertilizer Prices (τ_3): Five-year moving averages of an index of prices paid for fertilizer (nitrogen, potash, and phosphate). The index was constructed in the same manner as the output price index described above.

Agricultural Research (τ_4): Stock of agricultural research, measured with a five-year inverted-V lag structure to accumulate annual research expenditures in thousands of 1980 U.S. dollars. Alternatives considered include research expenditures accumulated with no lag and with a 9-year lag, and a five-year inverted-V lag structure to accumulate the number of research personnel in scientific man years.

Land Quality Index (τ_5): Peterson's (1987) international land quality index. An alternative measure considered is the soil-type weighted potential production of dry matter (WPDM) in tons per hectare for each country.

Human Capital (τ_6): The gross enrollment ratio for primary schools. An alternative measure of the quality of human capital considered is life expectancy.

To keep the data set as large as possible, we used regression interpolations to generate estimates of missing observations. A list of the specific sources, a detailed explanation of the data manipulation and a listing of the variables used in this analysis can be found in Elisiana, Fulginiti, and Perrin (1991).

Base Model Estimates: All countries and years are pooled together in a single equation of the form specified in equation (7). This pool gives a total of 410 observations, and the parameters are estimated with OLS. Although the error structure in equation (7) is uncorrelated with the variables representing inputs, its variance is not. The Breusch-Pagan (1979) test for heteroskedastic errors indicated that the null hypothesis of homoscedasticity cannot be rejected at the 5% significance level. Table 2 presents the parameter estimates of the model in equation (7). The table

[7] "International" dollars are obtained by FAO using the Geary-Khamis (see Elisiana et al., 1991) price index with the purpose of aggregating agricultural products for international comparison. The international average prices of agricultural commodities are determined simultaneously with the exchange rates of the national currencies in such a manner that the calculated exchange rates equalize the purchasing power of national currencies with respect to the defined groups of commodities.

[8] This measure of the agricultural labor input, also used in the other cross-country studies cited, is a crude one, uncorrected for hours worked and labor quality (education, experience, age, etc.). The only data series available to correct for quality differences through time and across countries are school enrollments and life expectancies, which are used in this study as alternative technology-changing variables that affect the productivity of labor.

TABLE 2.—LEAST SQUARES ESTIMATES OF EQUATION (7), 18 COUNTRIES

	Inputs					Intercept
	Land	Livestock	Machinery	Fertilizer	Labor	(α_0, α_k)
Linear terms (γ_{i0})	0.040 (0.083)	0.146 (0.114)	0.173 (0.061)	0.093 (0.051)	0.838 (0.093)	−1.964 (0.652)
Past Output Price (γ_{i1})	0.527 (0.044)	−0.554 (0.054)	0.064 (0.030)	−0.019 (0.024)	0.231 (0.048)	−2.266 (0.336)
Past Wages (γ_{i2})					−0.011 (0.003)	
Past Fert. Price (γ_{i3})				0.006 (0.006)		
Research (γ_{i4})	0.011 (0.016)	0.041 (0.022)	0.005 (0.013)	0.022 (0.009)	−0.140 (0.017)	0.523 (0.119)
Land Quality (γ_{i5})	0.054 (0.007)					
Schooling (γ_{i6})					0.040 (0.009)	

Note: Based on 410 observations during the years 1961 to 1985, standard errors in parentheses, overall $R^2 = 0.94$.

contains a total of 22 parameters, 12 of which are significant at the 1% level, 2 at the 5% level, and 2 at the 10% level. R^2 for the equation is 0.94 and collinearity diagnostics developed by Belsley, Kuh and Welsch (1980) indicate an absence of multicollinearity.

Elasticities of productivity with respect to technology changing variables can be evaluated at the mean value of input variables, using the coefficients in table 2 and equation (8). The results (table 3) show relatively small effects of the technology-changing variables. The productivity elasticities of greatest interest here are the ones representing the effects of past price expectations. They indicate that a 10% change in past output price expectations (due to different policy choices, for example) would produce a 1.3% shift of the production function, whereas increases in expected wages and fertilizer prices of the same magnitude would shift it down by 0.9% and up by 0.3%, respectively. This estimate of the effect of output price is consistent with the Schmookler-Lucas hypothesis and inconsistent with the "quiet life" hypothesis.

Quality of the soil and schooling have positive and significant effects on productivity while the coefficient of agricultural research, proxied as a five-year inverted-V lag structure of agricultural research expenditures, is negative but not significantly different from zero. The insignificance of this research variable is in marked contrast to significant positive effects estimated by Evenson and Kislev and by Antle (who used the number of scientific publications as the research variable), a point to which we return below. It is important to note that lagged price expectations in this model also serve as a proxy for research, and we obtain significant positive effects for that variable. In other words, these results indicate a significant impact of price-induced research, but not so for research measured by government expenditures.

Production elasticities evaluated at the average values of the variables are also presented in table 3. All are significantly different from zero. The sum of the coefficients is 1.06, very close to constant returns to scale. One of the main differences between the results of this study and previous ones is that we attribute lower production elasticities to labor and higher to land. Previous estimates of labor elasticity concentrated in the range of 0.35–0.42, although the estimates by Bhattacharjee and by Lau and Yotopolous were about 0.3, compared to our 0.25. Previous estimates of land elasticity have varied considerably. While the Lau and Yotopolous estimate was about 0.9 when country effects were included, Bhattacharjee's estimate was 0.36, the first Hayami estimates and those of Mundlak and Hellingshausen were about 0.2, and the remaining estimates were smaller, many near zero or negative. Our estimate of 0.25 is large relative to the majority of these. Our estimate of livestock elasticity is slightly below the average of others, our estimate of machinery elasticity is higher than most others, and our estimate of fertilizer elasticity is very close to the mean of previous estimates.

TABLE 3.—PRODUCTIVITY AND PRODUCTION ELASTICITIES
(evaluated at the mean, standard errors in parentheses)

	Regression Model	
	Variable Coefficient[a]	Fixed Coefficient[b]
Productivity elasticity for technology-changing variable:		
Past Output Price	0.13	
	(0.028)	
Past Wages	−0.09	
	(0.023)	
Past Fert. Prices	0.03	
	(0.028)	
Research	−0.02	
	(0.020)	
Land Quality	0.51	
	(0.065)	
Schooling	0.30	
	(0.071)	
Production elasticity for traditional input variable:		
Land	0.25	−0.10
	(0.036)	(0.027)
Labor	0.25	0.33
	(0.035)	(0.028)
Livestock	0.17	0.40
	(0.044)	(0.036)
Machinery	0.21	0.17
	(0.022)	(0.022)
Fertilizer	0.18	0.03
	(0.026)	(0.021)
Sum (traditional inputs):	1.06	0.83

[a] Equation (7).
[b] Equation (7) restricted by $\alpha_k = \gamma_{ik} = 0$ for all i and k.

The third column of table 3 shows the estimates of a fixed coefficients model, i.e., equation (7) restricted by $\alpha_k = \gamma_{ik} = 0$ for all i and k, as a contrast to those derived from the variable coefficients model. These results, particularly the negligible land elasticities, are similar to those of Evenson and Kislev in a similarly restricted aggregate output model, and to those of Kawagoe, Hayami and Ruttan for their subset of LDC countries. Lau and Yotopolous hypothesized that a lack of country-specific effects is the explanation for low land elasticity estimates from such a model, and upon introducing them into the KHR model and data the estimates of land elasticity rose to about 0.9. Since our variable coefficients model also includes country-specific effects via the land quality and other technology-changing variables, and it too yields higher estimates of land elasticity, our results support the Lau-Yotopolous hypothesis that the omission of country-specific effects biases the estimates of land elasticity downward.

The effect of price-induced technical change on the relative levels of input use is revealed by the net biases B_{n,τ_k} in equation (10). The estimated net bias parameters indicate that the effect of past price-depressing policies induced technical change that increased the cost shares of livestock and fertilizer (net bias parameters of -3.7 and -0.4, respectively) and reduced those of land, machinery, and labor (net bias parameters of 2.0, 0.1, and 0.7, respectively).[9]

Alternative Measures of Research and Resource Quality: Our base model estimates indicate a negligible impact of government research expenditures on productivity, contrary to expectations and to previous studies of returns to such expenditures (see Evenson (1989) for a summary of 73 such studies among LDCs). Thus we consider some alternative specifications, with results presented as equations (2) to (4) in table 4. Column (1) repeats the productivity and production elasticities previously described. In equation (2) we obtain the research stock variable as the simple cumulation of expenditures, with no lags. This results in a positive but still insignificant productivity elasticity, while a nine-year lag (column (3)) results in a negative elasticity. In regression 4 we switch to an alternative measure of research, man-years of government agricultural research effort, cumulated into a stock of research using a five-year inverted-V lag structure.[10] The productivity coefficient is in this case positive and significant, though still smaller than elasticities measured by Evenson and Kislev and by Antle.

These results suggest that there may be a positive productivity effect of public research activities (in addition to any price-induced productivity effect captured by our lagged price variable). The short lags here provide evidence supporting the hypothesis that agricultural research in developing countries is mostly of an adaptive nature

[9] Estimated pair-wise bias parameters are: land-livestock 5.31, land-machinery 1.79, land-fertilizer 2.91, land-labor 1.21, livestock-machinery −3.51, livestock-fertilizer −3.12, livestock-labor 4.11, machinery-fertilizer 0.40, machinery-labor −0.59, and fertilizer-labor −0.99.

[10] The scientific man-year measure might better measure intertemporal and cross-country differences in research effort than expenditures, if administrative overhead varies across time and space or if real salaries paid to researchers varies across time and space.

TABLE 4.—PRODUCTIVITY AND PRODUCTION ELASTICITIES UNDER ALTERNATIVE PROXIES FOR RESEARCH STOCK AND INPUT QUALITY
(standard errors in parentheses)

	(1)	(2)	(3)	(4)	(5)	(6)
Productivity Elasticities						
Past Output price	0.13	0.12	0.13	0.11	0.16	0.13
	(0.028)	(0.028)	(0.027)	(0.029)	(0.028)	(0.025)
Past Wages	−0.09	−0.10	−0.08	−0.11	−0.12	−0.08
	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)	(0.021)
Past Fertilizer price	0.03	0.02	0.05	−0.04	0.02	0.02
	(0.028)	(0.028)	(0.028)	(0.026)	(0.031)	(0.025)
Research						
5 years lag	−0.02				0.07	−0.07
	(0.020)				(0.022)	(0.019)
No lags		0.02				
		(0.021)				
9 years lag			−0.04			
			(0.018)			
Personnel				0.07		
				(0.019)		
Land quality						
Peterson's index	0.51	0.49	0.52	0.57		0.25
	(0.065)	(0.066)	(0.064)	(0.065)		(0.068)
WPDM					−0.37	
					(0.078)	
Human Capital:						
Schooling	0.30	0.29	0.29	0.31	0.21	
	(0.071)	(0.072)	(0.070)	(0.073)	(0.082)	
Life expectancy						2.42
						(0.259)
Production Elasticities						
Land	0.25	0.25	0.25	0.30	0.06	0.32
	(0.036)	(0.036)	(0.036)	(0.035)	(0.031)	(0.034)
Labor	0.25	0.25	0.27	0.14	0.40	0.45
	(0.035)	(0.036)	(0.035)	(0.034)	(0.032)	(0.040)
Livestock	0.17	0.18	0.17	0.23	0.19	0.10
	(0.044)	(0.045)	(0.043)	(0.043)	(0.046)	(0.041)
Machinery	0.21	0.19	0.24	0.13	0.18	0.15
	(0.022)	(0.022)	(0.022)	(0.019)	(0.023)	(0.022)
Fertilizer	0.18	0.19	0.18	0.21	0.09	0.19
	(0.026)	(0.026)	(0.025)	(0.026)	(0.028)	(0.023)

requiring a much shorter gestation and implementation period than is considered to be the case in developed countries. As regards the central focus of the present paper, however, it is notable that the various specifications of the research variable have no effect on the estimate of output price elasticity.

Equations (5) and (6) of table 4 consider alternative quality measures for land and labor. In equation (5) the Peterson land quality index is replaced by the Buringh measure of potential production of dry matter (*WPDM*), a variable that was also used by Mundlak and Hellinghausen. This variable yields a negative coefficient, suggesting that it is a very poor measure of aggregate land quality. Equation (6) shows that replacing schooling by life expectancy as a measure of human capital increases considerably the estimated impact of labor quality on productivity, the estimated labor production elasticity, and total returns to scale. For this study, much of the significance of table 4 is in the stability of the estimates of productivity elasticities for lagged output and input prices. The effect of lagged output price on productivity is consistently and significantly estimated at about 0.13, and the effect of lagged wages on productivity is also consistent and significant at about −0.09.

TABLE 5.—ESTIMATED PRODUCTIVITY CHANGES FROM ELIMINATION OF OUTPUT PRICE POLICIES

Country	Elasticity of Productivity with Respect to Output Price[a]	Price Changes due to Elimination of: Direct Intervention (%)	Price Changes due to Elimination of: Total Intervention (%)	Productivity Changes due to Elimination of: Direct Intervention (%)	Productivity Changes due to Elimination of: Total Intervention (%)
Argentina	0.257	31.3	66.1	8.1	17.0
Brazil	0.515	−6.6	15.2	−3.4	7.8
Chile	0.105	3.2	32.7	0.3	3.5
Colombia	0.028	11.9	48.5	0.3	1.4
Dominican R.	0.435	32.2	67.5	14.0	29.4
Egypt	0.577	75.7	114.3	43.7	66.0
Ghana	0.505	−7.8	32.1	−3.9	16.2
Ivory Coast	0.787	56.1	111.8	44.2	88.0
Korea	0.078	−34.8	−13.9	−2.7	−1.1
Malaysia	0.300	11.8	21.6	3.5	6.5
Morocco	0.345	26.1	52.2	9.0	18.0
Pakistan	0.133	32.9	88.8	4.4	11.8
Philippines	0.088	14.4	46.9	1.3	4.1
Portugal	0.250	28.0	22.8	7.0	5.7
Sri Lanka	0.379	33.2	97.4	12.6	36.9
Thailand	0.223	45.9	71.1	10.2	15.9
Turkey	0.338	−1.7	56.4	−0.6	19.0
Zambia	1.122	29.0	115.1	32.5	129.1

[a] Evaluated from equation (8), using estimated coefficients and mean value of inputs for each country.

B. Estimated Productivity Effects of Agricultural Policies

In this section we examine the implications of the base model (table 2) for evaluating the impact of various government policies on agricultural productivity. The previous theory suggests that the productivity of LDC's agriculture will be affected by policies causing implicit or explicit taxation of the sector. Evidence for a set of developing countries was presented in table 1. The nominal protection rate reported there is the multiple by which an index of domestic agricultural prices has been raised by government policies above a comparable index of international prices. These are Tornquist indexes constructed across commodities representing between 60% and 80% of the total value of agricultural output for each of the 18 countries in the series. The period analyzed covers the years 1961–84. The protection rates include the price effects of both direct commodity price interventions and the indirect agricultural price effects of real exchange rate distortions and protection afforded to non-agricultural commodities.

In general, the effect of a policy can be described as a percentage price wedge, that is, the difference between the expected demand price and the expected supply price in the period when decisions about the techniques to use are made, expressed as a percentage of the equilibrium price. We assume in this study that prices are exogenous to the agricultural sector so that the price wedges created by various policies can be characterized as exogenous price changes.

To evaluate the effects of policy wedges on the agricultural productivity of each country we multiply the productivity elasticities (column 1 of table 5) by the estimated policy-induced price wedges (columns 2 and 3 of table 5). The productivity elasticities are calculated using equation (8) evaluated at the mean of inputs for each country. Two price wedges are considered. Column 3 presents the average effect of direct government interventions, i.e., those aimed directly at the agricultural outputs. The total intervention wedge in column 4 adds to this the price effect of exchange rate policies and other interventions.

Elimination of direct (commodity-specific) interventions would have increased productivity in every country except those that have been subsidizing the sector. Brazil, Ghana, Korea, and Turkey have had direct subsidies, and elimination of those subsidies would have reduced price expectations, which in turn would have led to a lower rate of productivity increase in these countries. Indirect interventions have taxed agriculture in every country except Portugal, with the result that even in Brazil, Ghana, and Turkey the net effect of all interventions is to tax agriculture. Thus, all countries except Korea would have experienced an increase in productivity if all interventions had been eliminated. The estimated productivity increases range from 1.4% in Chile to 129% in Zambia.

IV. Conclusions

The central issue addressed by this study is whether past prices have a significant effect on the current productivity of agricultural resources. If they do, then the high taxation of LDC agricultural sectors over past decades would have reduced the productivity of LDC agricultural resources. The empirical results for a set of LDCs offer solid support for the hypothesis of a positive relationship between past output prices and current productivity, with the point estimate of productivity elasticity being 0.13. There was also solid support for the hypothesis that past wages have a negative effect on productivity, with a point elasticity estimate of about -0.09. These results are consistent with those of Schmookler and Lucas for non-agricultural industries in the United States.

The conceptual approach used to address the issue was an aggregate agricultural production function in which past prices and other "technology changing variables" determine the productivity of traditional inputs such as land, labor and capital. While prices have not generally been considered as a direct argument in production functions, it is quite plausible that if prices do affect the selection of techniques and technology in one period, then their effects might linger and thus be reflected in the productivity of conventionally-measured inputs in a subsequent period. The empirical estimates of the effects of prices on productivity were quite robust with respect to alternative proxies for other technology changing variables such as research, land quality, and human capital. Furthermore, the estimated production elasticities for traditionally-measured inputs are plausible a priori, consistent with those estimated in previous studies, and reflect approximately constant returns to scale. These characteristics lend support to the presumption that the estimates of additional output due to past prices do indeed reflect productivity changes, rather than the allocative effects of delayed supply response to past prices.

These empirical results have policy implications. Direct and indirect interventions in the sample countries over recent decades have been estimated to reduce agricultural output prices by as much as 50%. Given our estimates of productivity elasticities (evaluated for each country separately), the simple average productivity effect of these price-depressing policies could have been as much as 26%. This is a large effect, deserving of both corroboration by additional economic studies and of consideration by policy makers.

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